The longer excessive rains (24 hours) are due as a rule to any one of the following conditions: The advent of a tropical cyclone along the Gulf and the eastern seaboard. The seemingly fortuitous relative geographic position with reference to each other of a vigorous extratropical cyclone with a strong anticyclone immediately to the northeast. The same condition, although in a slightly different form, viz, the intrusion of an anticyclone (cold front) into an extensive barometric trough wherein high temperature and vapor content in the atmosphere prevail, also causes excessive rains for 24 hours and sometimes longer.

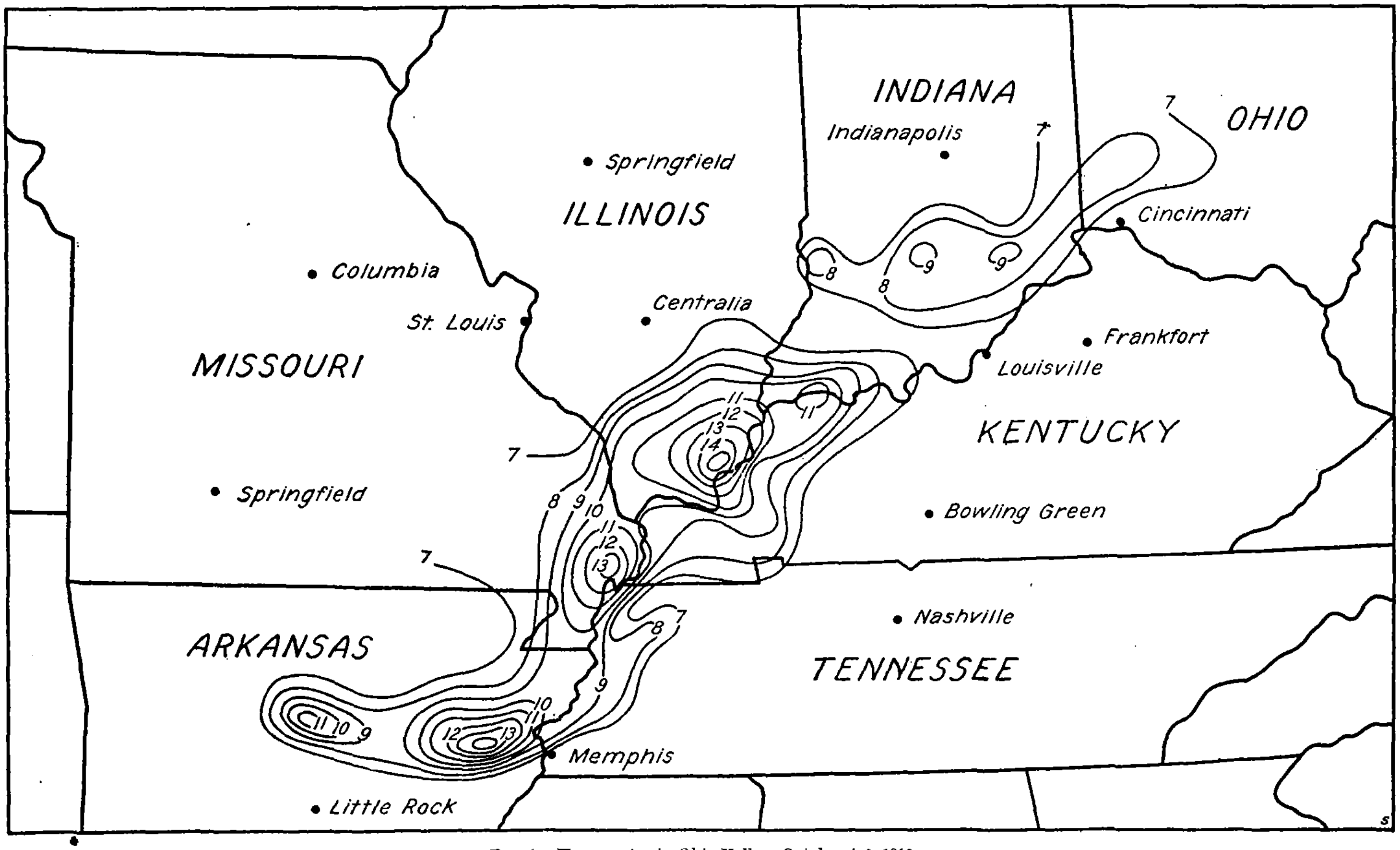

FIG. 4.—Heavy rains in Ohio Valley, October 4-6, 1910

RECOVERY FROM SUBNORMAL TEMPERATURES

By I. R. TANNEHILL

[Weather Bureau, Galveston, Tex.]

The cold wave having arrived, interest is directly turned to the rate of recovery to temperatures approximately normal. In some instances the cold lingers for days and the recovery is gradual while in other cases an abrupt change to much higher temperatures quickly follows. Public interest in the return to seasonable conditions is aroused not alone by its effect upon human comfort but because the rate of recovery is one of the factors determining the extent of injury to vegetation.

In discussing injurious temperatures, Young (1) says:

> So many factors must be taken into consideration in determining whether a given temperature will cause damage that the matter is one of great complexity. The length of time the low temperature persists, the vigor and stage of advancement of the plant, the kind of weather preceding the frost, and the rate of thawing all have considerable influence on the amount of damage that will be done.

The marked differences in rate of recovery from cold waves at Galveston is illustrated by the occurrence in January, 1887, of a temperature of 24° with only one day below freezing, while in January, 1886, the temperature was below freezing for seven consecutive days, with a minimum of 11°. The lower temperature in the latter instance was only in part responsible for the duration of freezing temperatures, as in February, 1899, the temperature fell to 8° with only three days below freezing.

This study was undertaken to determine the relative frequencies of temperature rises of various magnitudes, the relation of current temperature to the probability of a rise, and the influence of pressure distribution upon the rate of recovery from low temperatures.

As a basis for the study, all 7 a. m. temperatures in the period 1901 to 1925, inclusive, were examined, numbering 9,131 in all. Files of weather maps covered the periods 1901 to 1905 and 1914 to 1925, though not complete for the latter period. Weather maps and temperature changes in the winter months were studied chiefly, because at that season the frequency and average magnitude of temperature rises are greatest.

For the purposes of this paper a temperature rise is considered only when exceeding the stationary limit, namely, 10° in December, January, February, and March, 8° in April, May, October, and November, and 6° in June, July, August, and September. The rise is the difference in temperature from the 7 a. m. reading of one day to the 7 a. m. reading of the next following day. Temperature changes taking place between 7 p. m. readings were not tabulated.

Frequency of temperature rises.[1]—The frequency of temperature rises at Galveston is not large. For the year as a whole they occur on only about 4 per cent of all days. In the months of July and August rises exceeding the 6° limit are rare. The few that occur in June are chiefly due to showers that occur at or near the time of the morning observation, temporarily lowering the temperature below the normal, followed by a recovery before the following observation. Rises are most frequent in December, See Table 1.

TABLE 1[1]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1[2]	59	43	31	23	9	9	4	4	20	27	62	66
2[3]	2.4	1.7	1.2	.9	.4	.4	.2	.2	.8	1.1	2.5	2.6
3[4]	7.6	6.1	4	3.1	1.2	1.2	.5	.5	2.7	3.5	8.3	8.5

[1] Frequency of temperature rises, 7 a. m. to 7 a. m., in excess of stationary limits for 25 years, 1901 to 1925, at Galveston.
[2] Total number of rises exceeding stationary limits, by months.
[3] Average number per month for 25 years.
[4] Frequency in percentage—i. e., total number divided by total number of days; e. g., in January a forecast of stationary temperature would fail to verify on 7.6 per cent of all days because of temperature rises exceeding 10°.

The relatively large number in November as compared with winter months is partly due to the 8° limit. Proximity to the Gulf of Mexico is another cause of frequent temperature rises in November. Were it not for this influence it is likely that rises in temperature would be less frequent in autumn than in spring months, due to the tendency of the temperature downward in the former and upward in the latter. On his point, Cox (**2**) remarks:

> It should also be realized that with the advance of the seasons from winter to spring and summer there are more rises than falls, while with the approach of autumn and winter the reverse is true.

In the 25 years noted above there were 31 rises in March exceeding 10° and 62 in November exceeding 8°. In March there were 51 rises exceeding 8°, the November limit. In April and May combined there were 32 rises exceeding 8°, while in October and November there were 89.

In the autumn and early winter the land temperatures fall more rapidly than the water temperatures, and when the wind shifts to a southerly direction its temperature is higher, relative to air from the land, than in spring months, when the water remains relatively cool. This effect is evidently more pronounced than that of the advancing seasons. It is seen, also, in the relative frequencies of December and February rises—66 in the former and 43 in the latter. The effect becomes most pronounced in late spring when a north wind causes morning temperatures to fall and evening temperatures to rise. The temperature falls from 7 p. m. of one day to 7 p. m. of the next when the wind shifts from northerly to southerly. A forecast of "warmer to-morrow" at that season is not verified under the same pressure conditions as at other seasons.

Frequency of rises of various magnitudes in winter is shown in Table 2. Rises in excess of 20° are rare. Only eight were recorded in the 25 years of winter record. The maximum occurred on December 22, 1916 (32°).

[1] Rises are taken from the telegraphic reports. The Weather Bureau reports the temperature by telegraph to the nearest even number—odd numbers are not sent and if the number is exactly odd, as 69.0, the next lower even number is sent, 68.

In the records prior to 1901 this has been exceeded. In February, 1899, the temperature rose from 11.4° at 7 a. m. of February 13 to 45.7° at 7 a. m. of February 14, a rise of 34.3°, or from telegraphic amounts, 34°. At Galveston this is a phenomenal rise. Temperature falls, in cold waves, frequently exceed the greatest rises (**3**).

TABLE 2[1]

Amount of rise	Frequency of rises (25 years) in winter	Amount of rise	Frequency of rises (25 years) in winter
12 degrees	67	24 degrees	0
14 degrees	42	26 degrees	1
16 degrees	21	28 degrees	2
18 degrees	18	30 degrees	0
20 degrees	12	32 degrees	1
22 degrees	4		

[1] Frequency of rises of various amounts exceeding 10° from 25-year record in winter months. The telegraphic temperature was considered in determining the amount of rise—the temperature is telegraphed to the nearest even number and when exactly halfway between two even numbers—e. g., 71.0°—the next lower even number is telegraphed—70. Thus all rises are in even numbers as recorded on the weather map.

Relation of current temperature to probability of a rise.—It is well known that a rise in temperature exceeding the stationary limit is more likely to occur when the temperature is below normal than when normal or above. In winter, years 1901 to 1925, rises in temperature from 7 a. m. to 7 a. m. with relation to temperature of the

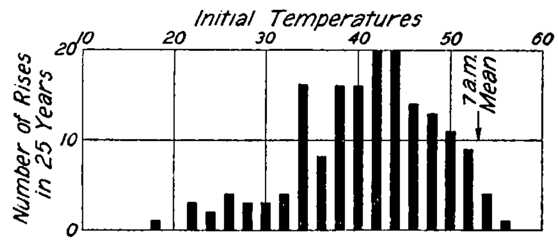

FIG. 1.—Number of temperature rises, 7 a. m. to 7 a. m., in winter, from various initial temperatures. Rises exceeding 10° only—i. e., from an initial temperature of 42° there were, in the 25-year period 1910 to 1925, 20 rises exceeding 10°

first observation have been distributed as shown in Figure 1. A change to warmer exceeding 10° has occurred most frequently from temperatures of 42° to 44°. The average 7 a. m. temperature for this period was 53°. Thus, rises occurred most frequently from readings 10° below the normal. However, this does not indicate the manner in which the probability of a rise varies with the temperature level. Temperatures of 42° to 44° occur more frequently than lower readings and therefore there is greater opportunity for a rise from that level.

A frequency distribution of 7 a. m. temperatures is shown in Figure 2. All the 7 a. m. readings in winter months, 1901 to 1925, inclusive, are used, totaling 2,256. The mode is at 62°, apparently, and the mean 53°. The distribution is decidedly unsymmetrical. In this, as in the preceding figure, only telegraphic amounts are considered. When actual temperatures are tabulated, the even readings preponderate, due to personal bias and to the rule for dropping decimals (**4**). These ininfluences are removed by using the even values as telegraphed, and it is probable that the irregularities in the distribution are purely chance and would be removed should a much larger number of observations be used.

Dividing the frequency of rises by the frequency of the initial temperature, we obtain the probability that the temperature will increase by more than 10°, as related to the temperature level—e. g., there were 80 occurrences of temperature 40° and in 16 cases the succeeding temperature was higher by more than 10°, making the probability 20 per cent.

Grouping the temperatures by 10° intervals and computing the probabilities, it is found that the probability of a rise increases as the temperature falls. See Figure 3. In 665 occurrences of temperatures from 60° to 68°, inclusive, there were no rises. There were 793 occurrences of temperatures 50° to 58° and only 25 rises, or about 3 per cent probability. It increases until at

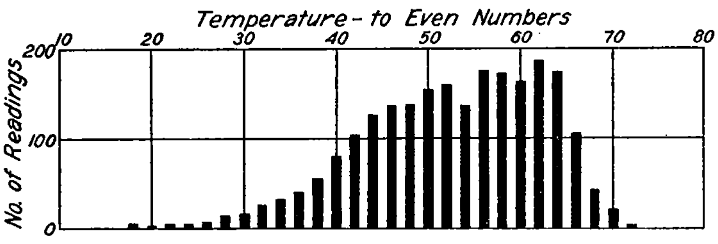

FIG. 2.—Frequency distribution of 7 a. m. temperatures in winter at Galveston, Tex., 1901 to 1925, inclusive

temperatures 20° to 28° the probability of a rise of more than 10° is 44 per cent.

In the entire record at Galveston, 1871 to 1925, there were six days with 7 a. m. temperature from 10° to 18°, inclusive, and in the 24 hours following four of these observations the temperature rose more than 10°, indicating that the probability of a verifying rise continues to increase as the temperature falls.

When the temperature is 50° or higher it is unlikely that there will be a verifying rise. Not only is this indicated by readings in winter months, but for all

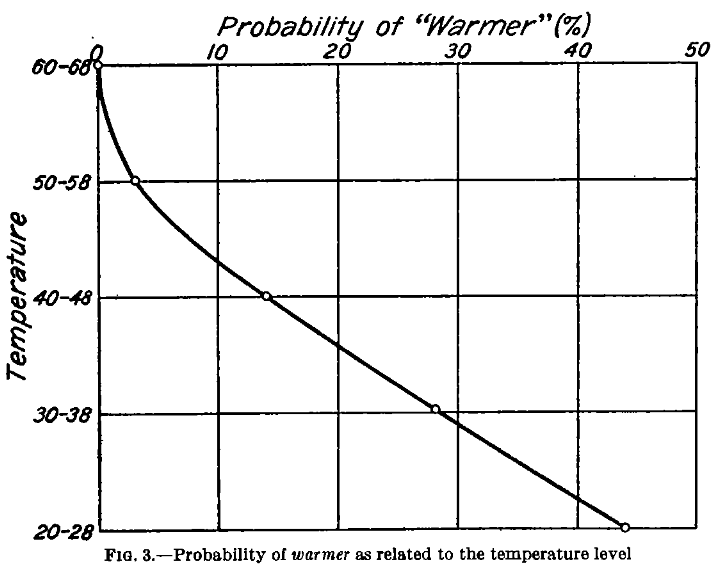

FIG. 3.—Probability of *warmer* as related to the temperature level

months rises from temperatures at or above the normal are quite rare. It may be stated positively that when the 7 a. m. temperature equals or exceeds the normal 24-hour mean for that day, the temperature in the ensuing 24 hours will not rise an amount exceeding the stationary limit for that season. In the 25 years studied there has been only one exception to this rule. The normal temperature for November 18 is 62°. On November 18, 1906, the 7 a. m. temperature was 64° and at 7 a. m. on November 19 it was 73.6°, showing an increase in telegraphic amounts of 10°, exceeding the 8° stationary limit for November. No other instance of a verifying rise from a temperature above the normal 24-hour mean has been found.

Tendency for subnormal temperatures to persist.—Though the tendency to rise increases as the temperatures become lower, the frequency of these rises is not in accord with the laws of chance. At temperature 40° the probability of a rise would be about 60 per cent, because there are 1,327 readings at and above 52° out of a total of 2,256, but the actual frequency of rises from 40° is only about 20 per cent. Therefore there is a strong tendency for an abnormal temperature to persist.

As an indication of the influence of the current temperature upon succeeding temperatures, all readings, 24 hours following temperatures of 64°, 54°, 44°, and 34°, have been grouped in frequency distributions in Figure 4. Following a temperature of 64° the mean 24 hours later was 58°, following 54 it was 55°, following 44 it was 47°, and following 34 it was 43°.

The temperature tends toward the normal, but in 24 hours insufficient time has elapsed for complete recovery. The farther the temperature departs from the normal the more rapid is its rate of return toward the normal in the average case.

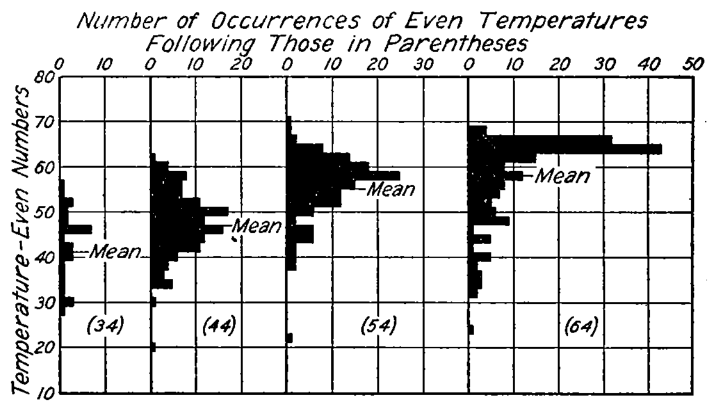

FIG. 4.—Frequency distributions of 7 a. m. temperatures 24 hours after an initial temperature of 64°, 54,° 44°, and 34°, in winter at Galveston, Tex., showing that the temperature tends to return to the normal, but the recovery in 24 hours is not complete

Point from which warm wave advances.—The cold wave which reaches the Texas coast with marked force arrives from the far Northwest, first appearing on the weather map as an "Alberta HIGH" and moving through the western portion of North Dakota or Montana (**5**). Strangely, the warm wave moves southeastward from precisely the same position. The temperature rise results partly from the flow of air from lower to higher latitudes, and this flow sets in first in the Northwest and progresses southeastward. There are other causes of the temperature rise. Speaking of the rise of temperature above the seasonal average, in advance of cold waves, Henry (**6**) said:

> The air is heated in front of a cyclone, not alone by the importation of relatively warm air from lower latitudes but as a result of other atmospheric conditions which operate to prevent loss of heat by radiation at night and to conserve the heat gained by day through solar radiation.

These remarks apply to the cyclone which follows the cold wave as well as to the one which precedes.

Conditions in advance of the temperature rise are shown in the following, from a study of a number of warm waves in the period 1901 to 1925. During these years there were in winter 20 instances in which the temperature rose 20° or more in 24 hours, 7 a. m. to 7 a. m. The dates, amount of rise, and initial temperature are shown in Table 3.

TABLE 3[1]

Date	Amount of rise	Initial temperature	Date	Amount of rise	Initial temperature
	°	°		°	°
Feb. 24, 1901	20	36	Jan. 14, 1916	22	34
Dec. 21, 1901	20	38	Dec. 22, 1916	32	26
Feb. 17, 1903	26	26	Feb. 5, 1917	20	28
Dec. 15, 1904	20	38	Jan. 7, 1918	20	36
Jan. 26, 1905	20	28	Jan. 12, 1918	28	18
Dec. 13, 1909	22	38	Jan. 18, 1918	20	38
Dec. 2, 1910	20	42	Dec. 11, 1919	28	38
Jan. 5, 1912	20	40	Feb. 21, 1921	22	40
Jan. 9, 1912	22	32	Jan. 8, 1924	20	40
Dec. 11, 1914	20	38	Dec. 23, 1925	20	34

[1] Greatest rises in temperature, 7 a. m. to 7 a. m., in winter, 1901 to 1925, inclusive All rises of 20° or more listed. Telegraphic temperatures used—i. e., all readings to nearest even number.

Weather maps are available for 13 of the above dates. From these a composite chart has been prepared showing the distribution of pressure at the beginning of the 24-hour period during which the temperature rose 20° or more. The high-pressure area which advanced southeastward with the preceding cold wave is shown over the middle and west Gulf region, with maximum pressure over southeastern Texas. The cyclonic depression appears in the far Northwest with minimum pressure at Helena, Mont. See Figure 5.

Temperature changes taking place in the preceding 24 hours are shown in Figure 6. This is a composite temperature change chart for 11 of the 13 cases grouped in Figure 5. Two maps were missing, due to the preceding day being a holiday, when no station map was drawn. The maximum temperature rise in the preceding 24 hours took place at Helena, Mont., 10°. The area of rising temperature extends southeastward into the northwestern portion of Texas. During this interval the temperature had continued to fall slowly at Galveston.

There can be no doubt, then, that the warm wave progresses southeastward from the same point as the cold wave. The one is attended by a flow of air from high to low latitudes and by atmospheric conditions which promote loss of heat through radiation, while the other is attended by a flow of air from lower to higher latitudes and by conditions which favor retention of the heat received through solar radiation.

Pressure indications.—It seems impossible to define with as great accuracy the pressure gradients favorable for a marked rise in temperature at Galveston in winter as is true of severe cold waves. The cold wave results from the transportation of air southward over considerable distances and the processes resulting in loss of heat are necessarily operative over a relatively long period of time. The source of warm air is, by contrast, near at hand. The temperature of the Gulf of Mexico is probably affected comparatively little at some distance from the shore, and immediately the wind is on-shore the temperature begins to rise. Slight pressure variations sometimes cause a shift of wind and a temperature rise that is quite local, the changes at Galveston frequently being out of harmony with those on the lower Texas coast. Low pressure in the middle or northern Rockies or the northern plains is, however, an essential. In the 94 cases of temperature rises exceeding the stationary limit in winter for which weather maps are available out of a total of 168 exceptions to this rule were rare. There were no instances of temperature rises exceeding the stationary limit when depressions were centered over the southern portions of New Mexico or Arizona, or in California or western Nevada, except when poorly defined and accompanied by well-defined depressions to the northward.

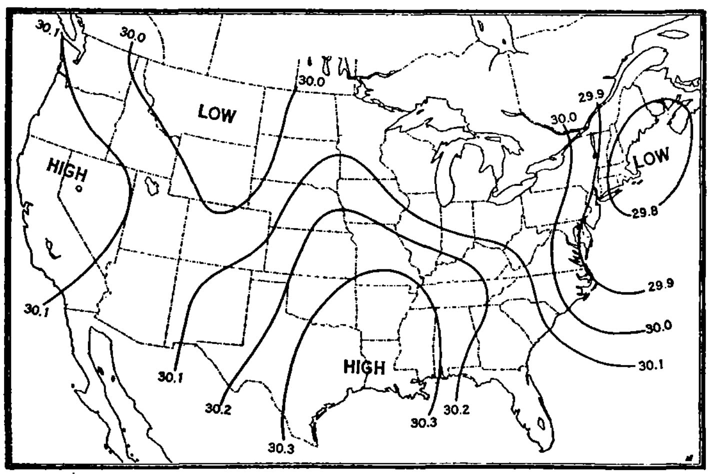

FIG. 5.—Barometric pressure at 7 a. m. preceding a rise in 24 hours of 20°, or more; composite of 13 pressure maps

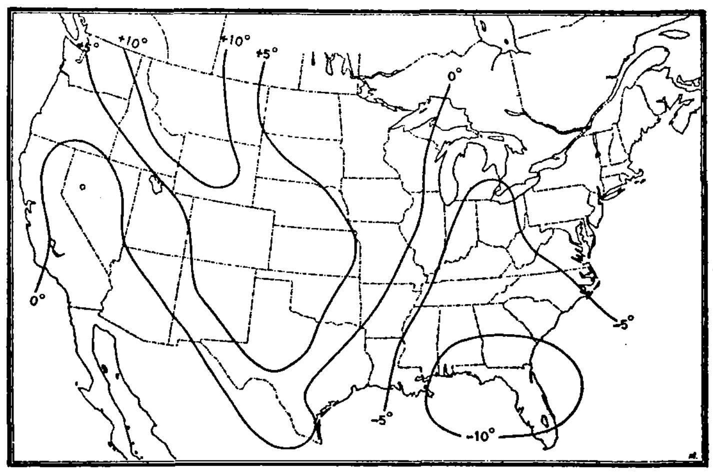

FIG. 6.—Average 24-hour temperature change, composite of 11 maps, during period immediately preceding 24 hours in which temperature at Galveston rises 20° or more

High pressure over the lower Mississippi Valley States and eastern and southern Texas is likewise an essential. The temperature must be below the normal, which condition requires the movement of at least relatively high pressure to that region. In 70 per cent of all cases the center of maximum pressure overlies that region, and when the center is over eastern or southern Texas or Louisiana and the temperature is below normal a rise is assured.

In more than 90 per cent of temperature rises exceeding the stationary limit, the center of maximum pressure had reached a line from Chicago to Del Rio. The farther northward on this line the center of the high crosses the less is the probability that the temperature will rise. HIGHS moving over northern sections produce smaller temperature changes and afford greater opportunity for the development of low pressure in the southwest, which is likely to result in continued cold weather.

The locations of high and low pressure areas in the 94 cases of temperature rise in winter are shown in Figure 7. The HIGH positions are indicated by dots, the LOWS by crosses. In nearly all instances of high pressure far to the north or east, there was an extension of the area southwestward into the lower Mississippi Valley or west Gulf region.

There is slow recovery from the cold wave when the cold extends to the west Gulf coast, but the center of maximum pressure remains in the North; when the HIGH moves slowly; when relatively high pressure persists over the northern Rocky Mountain region and when the succeeding LOW moves eastward near the southwestern border.

The temperature begins to rise within 24 hours after the center of the HIGH reaches a line joining Chicago and Del Rio, other conditions being favorable.

There is rapid recovery when the center of the high pressure area moves to southern districts and the succeeding LOW appears over the middle or northern Rockies or the northern plains.

Although the cold wave is attended by strong winds and in this latitude extreme cold is attained largely by importation of air from the northward, the warm wave is rarely attended by more than moderate winds. The highest wind recorded at the end of the 24-hour period

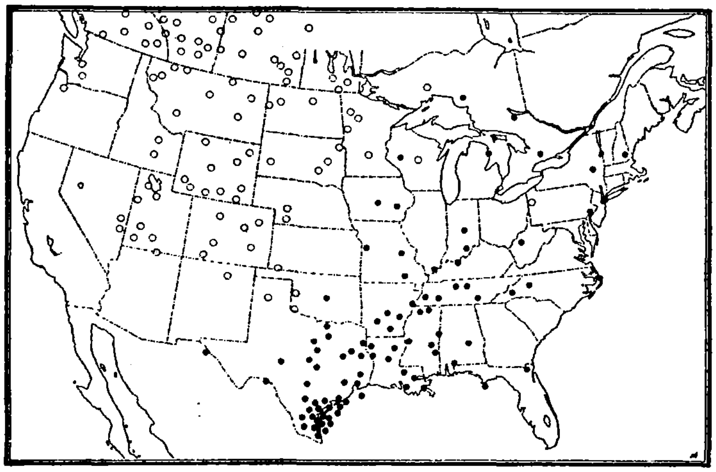

FIG. 7.—Positions of HIGHS and LOWS at 7 a. m. preceding 24-hour rise of more than 10° in winter—94 cases. Positions of HIGHS marked by dots; positions of LOWS shown by crosses

in which temperature rises of 20° or more occurred was 20 miles per hour. The average movement at 7 a. m. following the rise was 13 miles per hour.

Weather maps available for 12 cases in which the temperature was at or below 32° and in the ensuing 24 hours remained stationary or rose only 2° to 4°, were used to form the composite barometric chart in Figure 8. The conditions which are here unfavorable for a marked rise in temperature are: Location of the high-pressure crest slightly west of a line joining Chicago and Del Rio, maximum pressure at Oklahoma City; the location of the succeeding low-pressure area in the southwest, minimum pressure at El Paso; persistent high pressure over the northern Rocky Mountain region.

CONCLUSIONS

1. A temperature rise exceeding the stationary limit will not occur in any month unless the 7 a. m. temperature is below the normal 24-hour mean for that day.

2. Temperature rises are more frequent in autumn than in spring.

3. The lower the temperature the greater is the probability that it will rise, the percentage becoming approximately 50 when the temperature is 20°.

4. The "warm wave" advances from the same position as the cold wave and the low appears over the western portion of North Dakota and Montana, advancing southeastward.

5. The temperature begins to rise within 24 hours of the crossing of the HIGH center over a line joining Chicago and Del Rio, other conditions being favorable.

6. The recovery is rapid when the HIGH is broad in the south and narrow in the north, with the succeeding LOW in the northern Rockies or thereabouts.

7. Recovery is slow when the HIGH is broad in the north and narrow in the south and the LOW follows the southwestern border.

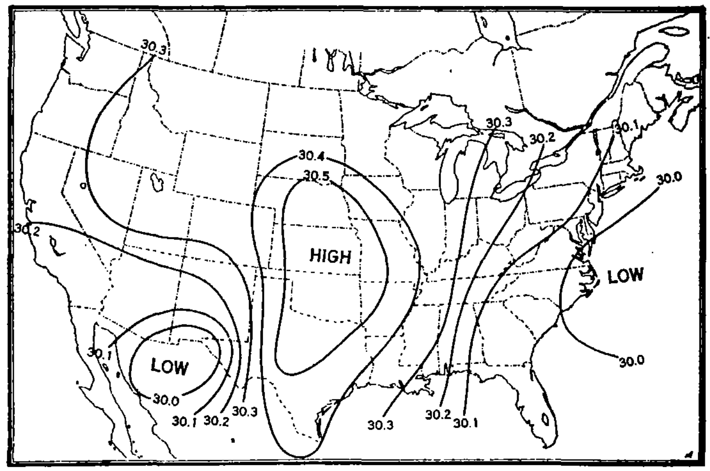

FIG. 8.—Composite of 12 pressure maps. Temperature at Galveston 32°, or below at 7 a. m. and rise in succeeding 24 hours 2° to 4° or stationary

8. When the center of high pressure overlies eastern or southern Texas or Louisiana and there is a well-defined LOW in the northwest, the temperature will rise rapidly if much below the normal.

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